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THESIS

AN ANALYSIS OF PERSONALIZED LEARNING SYSTEMS FOR NAVY TRAINING AND EDUCATION SETTINGS

by

Nathaniel J. Robbins

December 2016

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13. ABSTRACT (maximum 200 words)

The U.S. Navy employs a single approach to education and training in virtually all of its schoolhouses and learning environments. This "one size fits all" system is dated and inefficient, and the Navy could potentially benefit from an individualized approach. Personalized learning is a methodology that enables the individual student to learn in a manner that best suits his or her aptitude, background, and learning style. This approach, while complex and expensive to implement, is quickly gaining traction as educational technology improves. The benefits of such a methodology to student outcomes and organizational efficiency could be substantial.

In analyzing cost structures of three fundamental instructional models, long-run average total costs for each were found to be most sensitive to delivery of instruction, not content development or school infrastructure. Fewer human teachers, less travel time, more cost-effective delivery of training, and a higher level of student performance make personalized learning an attractive alternative to the industrial model. The Navy's Digital Tutor program is one such example, and although there are mixed results for its effectiveness and cost savings, evaluating this program provides lessons for continued efforts in embracing technology to develop revolutionary training and education programs for the future.

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AN ANALYSIS OF PERSONALIZED LEARNING SYSTEMS FOR NAVY TRAINING AND EDUCATION SETTINGS

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ABSTRACT

The U.S. Navy employs a single approach to education and training in virtually all of its schoolhouses and learning environments. This "one size fits all" system is dated and inefficient, and the Navy could potentially benefit from an individualized approach. Personalized learning is a methodology that enables the individual student to learn in a manner that best suits his or her aptitude, background, and learning style. This approach, while complex and expensive to implement, is quickly gaining traction as educational technology improves. The benefits of such a methodology to student outcomes and organizational efficiency could be substantial.

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LIST OF ACRONYMS AND ABBREVIATIONS

ADL	advanced distributed learning
AI	artificial intelligence
CAI	computer-assisted instruction
CBA	cost-benefit analysis
CMS	course management system
DARPA	Defense Advanced Research Projects Agency
DOD	Department of Defense
DT	digital tutor
DTP	digital teaching platform
ICT	information and communication technology
ICW	interactive courseware
IDA	Institute for Defense Analyses
IMI	interactive multimedia instruction
IT	Information Systems Technician
ITADS	intelligent tutoring authoring and delivery system
I-TRAIN	installation-training readiness aligned investments
ITS	intelligent tutoring system
ITTC	information technology training continuum
LCC	life cycle costs
LMS	learning management system
NETC	Naval Education and Training Command
NPV	net present value
O&M	operations and maintenance
PL	personalized learning
PSI	personalized system of instruction
ROI	return on investment
SA	systems administrator
SCORM	sharable content object reference model
SLE	synthetic learning environment
TAD	temporary assigned duty
VAKT	visual, auditory, kinesthetic, and tactile

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EXECUTIVE SUMMARY

As opposition to the "industrial-era" approach to education gains popularity, several emerging pedagogies and novel approaches to education stand poised to displace the traditional, one-size-fits-all classroom model for learning. Personalized learning (PL) is one such methodology, which seeks to enable the individual student to learn in a manner that best suits his or her aptitude, background, and learning style. This approach, while potentially complex and expensive to implement, is quickly gaining traction as educational technology improves. The benefits of such a methodology could be substantial, both in terms of student outcomes and of organizational efficiency. The U. S. Navy currently employs a single approach to education and training in virtually all of its schoolhouses and learning environments. This "one size fits all" system is dated and arguably quite inefficient in many cases, and the Navy could potentially benefit from a more individualized approach if implemented properly.

Technology-enabled individualized instruction can be more effective than traditional models; however, effectiveness is only half of the equation. The upfront costs of developing and implementing these tools are likely to be substantial, if not altogether prohibitive. In order to fully inform decision makers, both costs and benefits of programs must be presented. Unfortunately most assessments of educational solutions tend to focus on effectiveness, or potential benefits, without recognizing the costs (or cost savings) (Carey et al., 2007). We want our decision makers to efficiently allocate resources, which implies maximizing effectiveness for any given cost and minimizing cost for any given benefit. In order to accomplish this goal, they must understand the actual value of training provided by technology-based PL solutions.

A.   MOTIVATION

The education enterprise has historically lagged other industries in terms of technology adoption, creating an ever growing disconnect in experiences from academic environment to the workplace. Additionally, recent claims have surfaced that the current "millennial" generation not only has a drastically different relationship with technology,

but also fundamentally different ways of thinking and acquiring knowledge than previous generations (Prensky, 2001); this can render the current system ineffective for learning. Rapid advances in information and communication technologies (ICT) are fundamentally changing the nature of work in the military, with cognitive skills becoming increasingly important. Also, the recruits who enter the service are more and more accustomed to the integration of technology with their daily lives, they have come to expect the same in their school and work lives.

B.   UNDERSTANDING PERSONALIZED LEARNING

Bloom (1984) found that individually tutored students performed two standard deviations above the average conventionally taught student. In other words the average tutored student scored higher than 98 percent of the control group. This is commonly known as "the two-sigma problem," and the aim of technology-based personalized learning is to reclaim as much of that two standard deviation advantage as possible, not by hiring a dedicated teacher for every student, but rather by leveraging technology (Fletcher, 1992).

In a PL system, varied instructional actions are implemented based on student attributes to account for differences between learners. The observed learner differences that are typically used in prescribing PL solutions are intellectual abilities and prior knowledge, cognitive and learning styles, and motivation and other personality traits (Corno & Snow, 1986). Methods of accounting for these differences include altering or adjusting pace of instruction, difficulty of material, sequence of content presented, instructional strategy, and instructional delivery method (Wufleck, 2009).

In addition to improved learning outcomes, PL may also lead to greater efficiencies and cost savings in the training process. Evidence has shown that technology-based learning can affordably enable PL systems, and that these systems are not only more effective, but are also more adaptable and more flexible than traditional models. As a result, a "Rule of Thirds" can be used to estimate the effects of technology-based learning. The rule states that, in general, these applications will lower the cost of instruction by approximately one-third and either time-to-train will be reduced by one-

third, or the knowledge and skills gained will increase by one-third while time-to-train remains the same (Fletcher, 2010).

Technology-based PL can bring educational practices into the 21st century, ensuring that students are well prepared for the new challenges they will face in a technology-heavy, information dependent labor market. This sentiment applies equally to military members as to non-military members, if not more so. Our military's competitive advantage is increasingly tied to technological dominance, and skills required of our service members are heavily weighted in the cognitive domain (Fletcher, 2010). Maintaining operational adaptability in complex environments is paramount, and a system of learning that engages the active learner, encourages critical thinking, and requires demonstration of mastery before advancement is the key to defeating current and future adversaries (Department of the Army, 2011).

C.   INTELLIGENT TUTORING SYSTEMS

When properly implemented, technological tools have the power to maximize student potential, capturing the benefits of one-to-one tutoring that Bloom (1984) articulated. PL technologies that are responsive, that can adjust real-time to the learner's preferred style or speed, prior knowledge, and aptitudes, can ensure that all students reach their maximum potential with no time wasted, often at a cost savings (Dede, 2013).

Computer-assisted instruction programs that incorporate elements of artificial intelligence (AI) and machine learning to facilitate the understanding of student level of knowledge, response to individual needs, and teaching based on learning style or preferences, all in real time, are commonly referred to as Intelligent Tutoring Systems (ITS). Today's ITS can understand a student's thought processes, motivations, and emotions, essentially creating a mentor for every learner. Machine learning and data mining techniques also support this understanding of students and how they learn (Woolf et al., 2013).

Because of their inherent complexity and the need for such in-depth representation of the knowledge, development time and costs are major limitations of ITS. Estimates as high as 200 man-hours of construction time per one hour of instruction

highlight the requirement for significant upfront investments to develop an ITS (Fletcher, 2010). Clearly, there is a need for innovations in software development to mitigate potentially prohibitive costs of constructing ITS, and two possible solutions to the problem are common authoring tools and modularity.

The learner's progression through a PL program should be competency-based, with self-paced advancement occurring only after demonstrating mastery of the material. This progression is achieved by providing instruction in a manner best suited to both the subject matter and to the individual preferences of the learner. Finally, the learning environment should be malleable, facilitating important social interactions between peers and with the mentor, while enabling individual progress through the content.

D.   COST STUDIES

Cost studies combine an objective and quantitative determination of program effects with a thorough and detailed evaluation of costs, based on sound economic principles. Benefits, or impacts of the program, are compared with costs through a variety of methods to arrive at a net benefit or some other measure of value. The most commonly used types of cost study for educational evaluation is cost-effectiveness analysis, which compares non-monetary benefits to monetary costs. In general, a program is worth adopting if it demonstrates greater effectiveness for the same cost than the alternatives or status quo, the same effectiveness at lower cost, or the highest cost-effectiveness ratio (Ross et al., 2007).

Analyzing the relationship between cost components, such as fixed, variable, average total, and marginal costs provides another perspective for understanding the differences between human-tutoring, teacher-led classrooms, and technology-enabled personalized learning. Economies and diseconomies of scale become more apparent, as do the differences in unit costs of education. Also, we can better illustrate the benefits provided by PL, by describing each student's effective learning level as a marginal benefit. This basic microeconomic assessment of cost curves is intended to serve as a theoretical model for comparing and contrasting the cost behavior of differing approaches to instruction.

All three instructional models point out the critical concept that long-run average total costs are most sensitive to delivery of instruction, not content development or school infrastructure. Fewer human teachers, less travel time and cost, more cost-effective delivery of training, and a consistently high-level of student performance make PL a seemingly attractive alternative to the industrial model, although candidate programs should be analyzed on a case-by-case basis to determine individual viability before conversion.

E.   DIGITAL TUTOR CASE STUDY

The U. S. Navy's Digital Tutor (DT) program is an ITS currently in use in the initial technical training phase for Sailors in the Information Systems Technician (IT) rating, and represents one of the most advanced PL initiatives being undertaken by the military. A recent comparison of DT-trained Sailors with traditionally trained Sailors has raised some questions as to the effectiveness of DT, threatening the program's continued existence.

To determine the effectiveness of DT, the Institute for Defense Analyses (IDA) conducted an assessment comparing DT graduates to graduates of the traditional Information Technology Training Continuum (ITTC) and to Fleet-experienced ITs, in a series of exercises meant to replicate real-world problems. Overall, the DT subjects drastically outperformed the ITTC and Fleet groups, in some cases by a substantial margin. These results lead the authors to conclude that it is possible to develop real expertise in a drastically accelerated timeline and via ITS technical training only (Fletcher & Morrison, 2014).

While it was recognized that DT was quite expensive to develop and implement, the authors concluded that the cost in NPV of ITTC was 62 percent more per learner than DT training, or about $180,000. This difference would account for additional on-the-job training required by ITTC graduates to "catch up" with the DT cohort in experience level (Fletcher & Morrison, 2014). If this result is taken at face value, then perhaps the ROI justifies a high initial cost. Herein lies part of the problem with ITS like DT: they require a significant upfront investment and a longer timeframe to realize benefits.

In order to corroborate IDA's findings and to further assess the cost-effectiveness of the DT program, the Naval Education and Training Center (NETC) was tasked with completing its own assessment in 2016. NETC's study used survey data of recent IT A-school graduates and their supervisors, designed for Kirkpatrick level three evaluation of training transfer to job performance. The study compared the 27-week course containing the 18-week DT module to the 37-week traditional, SYSADMIN (SA) course. Additionally, cost data was collected and analyzed using a prototype, Navy-developed costing model. The findings suggested that, at best, DT was equally as effective as SA, but at a cost of $32,000 more per student. However, the benefits of getting a Sailor to the fleet 10 weeks sooner with DT were not considered; including these benefits would reduce the cost difference and enable a more realistic evaluation of the program (Department of the Navy, 2016).

F.   CONCLUSION

Findings from cost studies can help to bolster the public's confidence in DOD's management of taxpayer dollars. Without such information, funding agencies cannot make sound decisions regarding implementation of new education and training initiatives. When educational evaluators, not economists, consider costs of programs, there are often deficiencies with rigor, quantity, and quality. This weakens the usefulness of the evaluations, slows development of understanding of what is truly effective, and slows the policy making process (Ross et al., 2007).

Personalized learning approaches enabled by technology, such as ITS, have long demonstrated value as effective means of instruction, but little attention has been given to their overall cost-effectiveness (Angier & Fletcher, 1992). Rapidly advancing techniques in programming and AI, along with increasingly powerful and affordable computer hardware make these assessments difficult. Given technology's impact on other industries in recent past, the training and education segment should follow suit, allowing new tools to become more affordable every day. While the costs of DT may yet prove unsustainable today, we should not be discouraged from continuing to put forth effort in embracing technology to make our training and education programs second to none.

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I.   INTRODUCTION

Individualization is an educational imperative and an economic impossibility.

—Michael Scriven, 1975

A.   BACKGROUND

As opposition to the "industrial-era" approach to education gains popularity, several emerging pedagogies and novel approaches to education stand poised to displace the traditional, one-size-fits-all classroom model for learning. Personalized learning is one such methodology, which seeks to enable the individual student to learn in a manner that best suits his or her aptitude, background, and learning style. This approach, while potentially complex and expensive to implement, is quickly gaining traction as educational technology improves. The benefits of such a methodology could be substantial, both in terms of student outcomes and of organizational efficiency. The U. S. Navy currently employs a universal approach to education and training in virtually all of its schoolhouses and learning environments. This "one size fits all" system is dated and arguably quite inefficient in many cases, and could potentially benefit from a more individualized approach, if implemented properly.

In this study, I will outline both how and why individualized instruction can be more effective than traditional models, and also discuss some of the ways that technology can enable it; however, effectiveness is only half of the equation. The upfront costs of developing and implementing these tools are likely to be substantial, if not altogether prohibitive. In order to fully inform decision makers, both costs and benefits of programs must be presented. Unfortunately most assessments of educational solutions tend to focus on effectiveness, or potential benefits, without exploring the cost side, to include cost savings (Carey et al., 2007). As with all programmatic decisions, the problem is one of simple economics. We want our decision makers to efficiently allocate resources, or maximize effectiveness while minimizing resources expended. In order to accomplish this goal, they must understand the true and complete value of training provided by technology-based PL solutions, relative to the costs of these training and education

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efforts. This is even more important in an era of fiscal conservatism, when accountability is paramount.

B.   RESEARCH QUESTIONS

In this thesis, I will attempt to answer the following questions regarding the implementation of personalized learning in Navy training and education settings:

1.   How might personalized learning affect student outcomes and organizational efficiency within Navy training and education environments?

2.   How can current and future educational technology enable the use of personalized learning systems within the Navy?

3.   What methods of cost analysis are best suited to evaluating technology-enabled personalized learning systems for Navy use?

C.   ORGANIZATION

The remainder of this thesis is organized into five chapters. In Chapter II, I review the literature surrounding learning science, generational differences in learning, and benefits of individualized instruction. Chapter III introduces some technology-based solutions that have been implemented to personalize training and education, including some that are specific to DOD. Chapter IV describes the types of cost studies used to evaluate educational programs, and outlines a model for analyzing cost components of alternative courses of action. Chapter V compares two studies of the U. S. Navy's Digital Tutor program, pointing out strengths and weaknesses of each and recommending methods for improving these types of evaluations. In Chapter VI, I make some final recommendations for further study and use of personalized learning approaches, as well as closing remarks.

II. LITERATURE REVIEW

Our current educational norm has been an "industrialized," one-size-fits-all education model that dates back to the 19th century and in which information is presented to a group of students in lecture format while they listen passively with minimal or no participation. This type of education is a far cry from the days of Aristotle, when the standard was one-to-one tutoring and use of the Socratic method—critical questioning to allow the pupil to arrive at knowledge on his or her own, rather than having it "transferred" directly from the teacher (Murphy, 2006). The shift over the generations has had primarily economic motivations, particularly in the United States during the industrial revolution, when Horace Mann's common school model for mass education gained popularity in the 1830s as an efficient means of producing future factory workers (Murphy, 2006).

This model has been challenged in the past for its lack of effectiveness, namely by John Dewey's progressive movement of the early 20th century, touting a child-centered pedagogy (Apple & Teitelbaum, 2001), Keller's personalized system of instruction (PSI) (1968), and Corno and Snow's adaptive teaching (1986). More recently, a wave of initiatives, studies, and new policies promote a learner-centric environment in which instruction can be tailored to the student's past experience, competence, learning style, pace, and other attributes. These alternative methods promise to reform the education system by producing better students more quickly, and students who are more prepared to thrive in a workplace where rapid technological advance is the norm and critical thinking skills are ever more in demand.

The education enterprise has historically lagged behind other industries in terms of technology adoption, creating an ever-growing disconnect in experiences from academic environment to the workplace. Additionally, recent claims have surfaced that the current "millennial" generation not only has a drastically different relationship with technology, but also fundamentally different ways of thinking and acquiring knowledge than previous generations (Prensky, 2001), thereby rendering the current system ineffective for learning (Department of the Air Force, 2008).

In an often-cited randomized controlled trial, Bloom (1984) found that individually tutored students performed much better than those taught in a traditional classroom format. In fact, the average tutored student was two standard deviations above the average conventionally taught student, as shown in Figure 1. In other words, the average tutored student scored higher than 98 percent of the control group. This is commonly known as "the two-sigma problem," and the aim of personalized learning and other methods is to reclaim as much of that two-standard-deviation advantage as possible—not by hiring a dedicated teacher for every student, but rather by leveraging technology (Fletcher, 1992b).
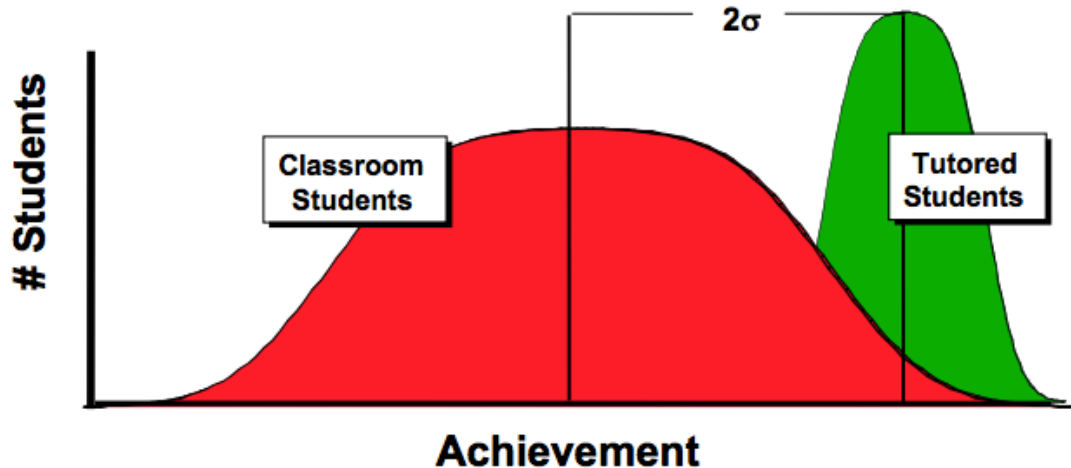
Figure 1. Student Achievement Distribution Based on Type of Instruction.
Adapted from Fletcher (2010).

Two primary factors are believed to account for this difference in outcomes. The first is level of interactivity between teachers and students, as measured by the number of questions a teacher and students may ask of each other during an hour of instruction (Oblinger & Oblinger, 2005). Graesser and Person (1994) found that students were only able to ask about .1 questions per hour in a classroom setting, compared to 20–30 in a tutored session. Teachers asked an average of three questions per hour of their class, while this number jumped to 120–145 questions asked of a single student in an hour of one-to-one tutoring. The second factor is the tailoring of pace, sequence, and content to

the students' needs (Fletcher, 2010). A tutor is able to fluidly alter speed of instruction, delivery method, or content based on continuous assessment of their students' progress, easily discerning any difficulties along the way. The solutions to personalized learning technology I present in this paper will address both of these factors, although the second is more aligned with the overt objectives of most personalized learning systems.

Today, individualization, personalization, customization, and differentiation are used to describe teaching and learning strategies as solutions to the outdated, one-size-fits-all model of education. Often used interchangeably, there is no agreed-upon definition of these terms. Typically, however, *individualization* refers to pace of instruction alone, while *differentiation* suggests adjusting the learning approach based on the learner's interests, abilities, or learning style. *Personalization* can be thought of as the combination of both individualization and differentiation (U.S. Department of Education, 2010; Grant & Basye, 2014). For purposes of clarity, I will use the term "personalized learning" (PL) to encompass any and all types of tailored approaches to education, including pace, learning style, background knowledge, abilities, preferences, or any other attribute which may be used to adjust to the individual. These alternatives to the current classroom-learning environment seek not only to simply modernize outdated mass education models, but to leverage technology to transform formal education into an individualized, learner-centered endeavor as it was intended more than 2,000 years ago, "an Aristotle for every Alexander" (Fletcher, 2010).

A.   CULTURAL SHIFTS AND DRIVERS FOR CHANGE

Rapid advances in information and communication technologies (ICT) are fundamentally changing the nature of work in the military, with cognitive skills becoming increasingly important. Also, as recruits are entering the service more and more accustomed to the integration of technology with their daily lives, they have come to expect the same in their school and work lives. Technology adoption in training and education has historically lagged most other industries (Domenech, Sherman, & Brown, 2016; Oblinger & Oblinger, 2005). Furthermore, some argue that the millennial

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generation's lifelong exposure to ICT has made the current education system ill equipped to properly teach them, and that a radical generational shift in learning has occurred.

The term, "digital natives," has been used to describe members of the current generation born after 1980. Also known as the net gen or millennials, these are individuals who have never known a world without the Internet, who grew up connected and surrounded by ICT (Oblinger & Oblinger, 2005). They are said to be experts in the use of technology, accustomed to receiving their information digitally, and that they are more active, experiential learners rather than passive. They like to work in teams and have social connections, and need to be interactive, whether with other people or with their technology (Oblinger & Oblinger, 2005). Some have argued that this prolonged exposure and use of ICT from an early age has altered the way that the entire generation learns. Prensky (2001) claimed that digital natives "think and process information fundamentally differently from their predecessors." Presnky and supporters believe that the education system must evolve to accommodate this dramatic change in students' learning styles (Brown, 2005; Roberts, 2005).

The "gamer generation," also digital natives, grew up playing video games, a particularly powerful form of ICT due to their high level of interactivity. According to Carstens and Beck (2005), playing games during the formative years of early childhood through adolescence has "hard wired" them, forming neural pathways differently than earlier generations. They have a different belief system, modeled around competition and winning, heavily influenced by years of gaming. Consequently, new tools are needed to teach this new generation, and one recommendation is to include experience-based learning, which is broken up into small units and self-paced to the individual learner, in much the same way as games are paced to the player's level of skill. They also need more interactivity, whether with people or technology. These traits and needs are consistent with descriptions of digital natives, but give us a slightly narrower perspective.

Although these claims make sense intuitively, several studies have found little scientific basis behind them (Bullen, Morgan, & Qayyum, 2011; Corrin, Lockyer, & Bennett, 2010; Pedro, 2006). Bennett, Maton, and Kervin (2008) found that youth use of technology was lower than expected, and that it was not universal across the generation,

but varied widely. A meta-analysis by Bullen et al. (2011) could not locate any empirical evidence to support claims that the millennial generation is fundamentally different in behavioral characteristics or learning preferences. Both studies found that the primary factors influencing a person's use of ICT were socio-economic status, ethnicity, gender, age, and access to technology, not generational membership. For the most part, research has shown that, on an individual basis, learning styles vary widely and are not generalizable to an entire generation. Additionally, learning styles change over time, or are situation dependent, making the claims of generational specific style even less credible (Pedro, 2006). More information on learning styles and their relevance to PL can be found later in this chapter.

Another study by Corrin et al. (2010) of those born after 1980 found there was wide variation in how students rated their own aptitude with technology. Access to technologies such as laptop computers and smart phones was found to be essentially ubiquitous in this case, so although most everyone had access to the technology, their level of competence was not homogenous. Also, subjects tended to use their devices much more for everyday life than for academic purposes, but this could be attributed to lack of requirements or accommodations in the academic setting as much as the students choosing not to adopt tech for use in school. The variety of aptitude, access, and use of ICT in and out of school found in this study show that the digital native generalizations may be unfounded, although it raises the question: if the technology were available and supported in schools, would students even want to use it?

Cengage Learning (2010) conducted a survey to determine how technology-based learning affects student engagement and learning outcomes in higher education. The survey showed that, although 70 percent of students do prefer a learning environment that uses a great deal of technology, there must be adequate support for students to use the tech. Teachers assumed that students were more tech-savvy than they believed themselves to be, and students felt that ICT in the classroom was under supported by the school (Cengage Learning, 2010; Cengage Learning & Eduventures, 2010). Margaryan, Littlejohn, and Vojt (2011) found no evidence to show that students were generationally different in the way they created and shared knowledge, and that their preferences for use

of ICT in the classroom was actually driven more by their instructors' preferences than any other factor. The students tended to conform to both the pedagogy and technology level that the teacher dictated. By contrast, Usher (2012) reported that the addition or use of technology, such as games and other interactive multimedia experiences in schools, could have positive motivational effects on students. These interactive technologies, because they can be readily modified, adjust to a student's individual skill level, in addition to fostering teamwork and communication. The net-gen feels that a core attribute of technology is that it is customizable and able to adapt to their needs (Oblinger & Oblinger, 2005). While education in general can certainly benefit from technology-enabled programs, the emphasis should be more about increasing effectiveness for the individual learner, rather than accommodating a generation believed to be fundamentally different.

Constant use and exposure to ICT is likely to change how anyone communicates, learns, and socializes, regardless of age or generation (Pedro, 2006). Oblinger and Oblinger (2005, p. 2.9) remarked, "We are all products of our environment-and technology is an increasingly important part of that environment." However, the question remains, does education need to change because the students are somehow profoundly different than what the system was designed to teach? Every generation has its own social norms and cultural practices, and millennials are no exception. Interaction, social and with technology, seems to be an important theme for net gen learners. Students perform better and retain more when they actively participate in the construction of their own knowledge (Oblinger & Oblinger, 2005). This is supported by the evidence, which has shown that interaction with instructors is much higher in the one-to-one setting, and virtually non-existent in a lecture-based classroom (Graesser & Person, 1994). It has also been shown that technology use is greater in students' everyday lives than in school (Margaryan et al., 2011). At home, they are actively engaged in the digital world, finding their own way to new knowledge, while in school, they are typically subjected to passive learning devoid of context.

The problem is that not enough schools and teachers are embracing the tools available, while the rest of the world has done so with gusto. Students not exposed to

certain types and uses of ICT while in school might find themselves at a disadvantage when entering the workforce. Digital literacy and familiarity, by nature of widespread technological advance, are becoming required basic skills for employees, and the education system must understand this. The Army and Air Force have both recognized this imperative, though perhaps placing too much emphasis on the presumed generational shift (Department of the Army, 2011; Department of the Air Force, 2008). Important to remember is that the majority of millennials, along with many Gen-X and Baby Boomers, do indeed have an elevated comfort with technology, and that can be leveraged to implement PL systems that tailor instruction to the student's prior experience, preferred delivery method/pace, and aptitudes. Using ICT to make training and education more active, social, and learner-centered would address DOD priorities that its service members be more adaptive, creative, and able to think critically to ensure our military's dominance in the 21st century (Department of the Army, 2011; Department of the Air Force, 2008; Department of the Navy, 2012).

B.   LEARNING THEORY AND PL TREATMENTS

In this section, I will review PL systems that tailor instruction to the student based on one or more individual attributes. In a PL system, varied instructional actions are implemented based on student attributes to account for differences between learners. I will also describe some of the most common differentiating characteristics for PL and corresponding methods of adapting instruction. The observed learner differences that are typically used in prescribing PL solutions are intellectual abilities and prior knowledge, cognitive and learning styles, and motivation and other personality traits (Corno & Snow, 1986). Methods of accounting for these differences include altering or adjusting pace of instruction, difficulty of material, sequence of content presented, instructional strategy, and instructional delivery method (Wufleck, 2009). These attributes and prescriptions will all be discussed further, but first a brief synopsis of learning and instructional theory will lay the foundation for further analysis.

1.   Learning Science

At the turn of the century, industrial age education was intended to prepare large numbers of future factory workers to perform simple, repetitive tasks through a process of remember and repeat. These workers were far more likely than today's laborers to remain in one single profession for the entirety of their working lifetime (Oblinger & Oblinger, 2005). This "transmission paradigm" of passive learning is most closely linked with behaviorism, the prevailing theory of learning and psychology through the 1950s. Behaviorists, such as John Watson and B.F. Skinner, sought to maintain scientific credibility by only acknowledging those reactions that could be objectively observed and measured (Tennyson, 2010). Internal, cognitive processes were necessarily ignored, and therefore, a stimulus-response reinforcement model of learning was adopted. This method focused on inputs to the environment, or rewards and punishments, which could be used to produce a desired learning outcome (Pritchard, 2014). Critical thinking was not prioritized, as knowing took precedence over understanding. Simply achieving the desired behavior via conditioning and reinforcement was considered a success.

In the postindustrial age characterized by rapid technological advance, critical thinking, problem solving, and persuasive expression gained importance in educational circles. These "new" skills came to define an era of understanding, rather than knowing, and behaviorism gave way to constructivism as the dominant theory of learning (Tennyson, 2010). The constructivist theory, with roots in cognitive science, espouses that learners 'construct' new knowledge by taking in information and using it to build on to their pre-existing knowledge, understanding, and experiences (Brown, 2005). This is nearly a direct antithesis to the transmission paradigm of the past, and emphasizes that effective learning is an active, not a passive process. Additionally, context is important, both from the student's reflection on prior knowledge and from the realism of the educational setting (Domenech et al., 2016). Finally, learning is a social and collaborative process, where interaction with teams, teachers, experts and peers are critical to constructing new knowledge. Learner engagement at every level and control over the process are key requirements for a constructivist approach (Brown, 2005).

Constructivism has continued to dominate the field of learning science and has heavily influenced instructional theory and instructional systems design over the past 30 years. Designing learner-centric systems that account for and interact with a student's prior knowledge and experience have become more and more common. However, aspects of behaviorism have proven viability in certain situations, and integrated instructional design theories attempt to synthesize aspects from multiple educational models to accommodate an individual's learner's progress at achieving a specific desired learning outcome. Technology has enabled the advance of these integrated theories with the creation of interactive, intelligent learning systems. These flexible, adaptable programs will be discussed in Chapter III, and further support the constructivist position of active learning in a responsive and interactive environment, built upon the individual's past knowledge and experience (Tennyson, 2010).

2.   Aptitude Variables

Corno and Snow (1986) define three broad categories of aptitude variables related to educational performance: cognition, conation, and affection. These variables are the individual characteristics to which instruction can be tailored in PL systems. Cognition, or the process of acquiring knowledge (Pritchard, 2014), includes intellectual abilities and pre-existing knowledge. Conation, meaning natural tendencies, covers cognitive and learning styles, and affection, referring to feelings and emotions, includes motivation and other personality traits. These variables combine in complex mixtures unique to every person to account for one's performance in a given learning situation. Another concept of educational performance is Gardner's multiple intelligence theory, which says that intelligence is based upon a mix of aptitudes across nine different intellectual categories: linguistic, logical/mathematical, musical, spatial/visual, kinesthetic, interpersonal, intrapersonal, naturalistic, and existential (Pritchard, 2014). These traits are closely linked to modalities of learning, and will be discussed along with cognitive and learning styles. The majority of research has focused around understanding this category, and how these differences might be leveraged to gain positive effects on individuals' learning outcomes.

a.   *Cognition and Learning Styles*

Cognitive and learning styles are often conflated and mistakenly used interchangeably, but the terms are not synonymous. Cognitive styles are higher-order classes that refer to the way that a person typically processes information and solves problems, and are considered to be stable over the long term (Holden, 2011). The primary styles that have been identified are field-independent and field-dependent. Field-independent style, briefly, describes detail-oriented individuals who are analytical, rational thinkers that focus at the task level. Conversely, field-dependent individuals think holistically and approach problems from a more global perspective. They see the bigger picture, but may lose sight of the finer details (Pai, Adler, & Shadiow, 2006). Though not specifically descriptive of a learning situation, cognitive styles do inform and influence the individual's learning style, or the preferred/most effective way a person processes information to create knowledge.

Learning styles have been recently popularized in the literature as the primary means by which to personalize learning. Proponents contend that matching teaching styles to the individual learning styles of students is the surest way to solve the two-sigma problem. Others claim that this could be limiting, and propose that a student or teacher's awareness of their own learning styles enable them to be more effective in the present-day classroom. This point comes from the concept of metacognition, or thinking about one's own way of thinking (Pritchard, 2014). With knowledge about how one's own mind works, particularly in an academic environment, that individual is able to develop an approach to learning that works best for them. Metacognition allows a deeper level of engagement with the learning process, motivating and enabling a student on the path of lifelong learning (Manacapilli et al., 2011).

In order to better understand learning styles, Coffield, Moseley, & Hall (2004) conducted a meta-analysis of the research from this complex and widespread field. They reviewed 71 learning-styles models for reliability, validity, and effectiveness by consolidating the results of thousands of professional papers and reports, and directly referencing 631 sources. The group divided the original 71 models into five families of learning styles, based on their underlying theories. Thirteen representative models,

deemed to be the most significant of the entire group, were then chosen to review in-depth. The findings from this meta-analysis suggest that the field of learning styles research is not at all consolidated, and at times contradictory and contentious. Even the final group of 13 could not be further merged into a single, coherent theory on how people differ in their approaches, characteristics, and tendencies towards learning. While this result isn't conclusive, the report does find sound evidence that there are many legitimate differences among learners, and that further study and agreement on these differences could lead to benefits in the future of education and learning.

One popular subset of learning styles is modalities, which delineates the individual's preference for sensory input of information. These input channels are visual, auditory, kinesthetic and tactile, and are typically combined in some form of multi-sensory processing as a preference for taking in information. This model, typically referred to as VAKT, has been used in many cases to personalize e-learning systems to individual learners' pedagogical needs. A review of one such platform by Peter, Bacon, and Dastbaz (2010) found potential benefits, but agreed that the field is too dispersed and that not enough data exists as to which learning style model is the best, or most effective for these applications. A study conducted by Becker, Kehoe, and Tennent (2007), also using a VAKT model, concluded that a student's learning style did not seem to affect their preference for alternative delivery methods of instructional content. However, they did find that traditional methods of classroom instruction tend to be favored only by those with learning styles that match, like aural. There are many more examples of research since the 1960s on learning styles that have produced similar, inconclusive results, leading Coffield et al. (2004), Tobias (1989), Holden (2011), and others to conclude that the benefits of personalizing instruction to individual learning styles have been exaggerated at best, and at worst, is a wholly ineffective practice. In a critical and thorough review of learning styles research, cognitive psychologists, Pashler, McDaniel, Rohrer, and Bjork (2009, p. 105) found "no adequate evidence base to justify incorporating learning styles assessments into general educational practice." All agree that much more concentrated inquiry is needed in this realm, and recommend that the research methods also be carefully considered beforehand. Additionally, there may be

evidence to show that educators can optimize learning outcomes simply by ensuring the delivery mode is consistent with the content and overall learning objectives, without regard to individual student differences (Hays, 2006). This has been also linked to a multi-modal approach to instruction, in which delivery mode is varied throughout the course of instruction, ensuring that students with different preferences will be exposed to their optimal style enough to adequately engage with and grasp concepts being taught (Pritchard, 2014).

b.   *Prior Knowledge and Learning Speed*

In addition to conation and learning styles, individuals express differences in cognition, including intellectual abilities and existing knowledge, which may be used in PL settings (Corno & Snow, 1986). While intellectual ability, such as types of intelligence, is a complicated and not well-understood area, prior knowledge does show great promise for explaining differences in learner outcomes (Snow, 1986). Past experience, according to Tobias (1989), may account for much of the disparity in speed of learning among students, and is a critical variable in how a person gains new knowledge. The gap in learning speed has been shown to reach ratios of more than 4:1 between fastest and slowest students, highlighting the importance of adjusting pace of instruction to the individual (Fletcher, 2010). Students with a low level of applicable prior knowledge simply require more instructional support and time to understand new concepts.

PL systems that adjust pace of instruction may lead to overall better learning outcomes for students, in addition to time and cost savings mentioned earlier with the Rule of Thirds. A pioneer in individualized education, Keller (1968) created his personalized system of instruction (PSI) as an alternative to conventional approaches to teaching, to allow students to work completely at their own pace through a course of study with set term length. Before advancing to new material, they were required to demonstrate mastery of the current module. Although lectures were used sparingly, and only as a source of motivation, students did have many more, less formal interactions with instructors and facilitators than with conventional teaching, keeping engagement at a

high level. A student would be assessed nearly continuously throughout the term, but as each assessment carried a very low weight, it was not considered a stressful ordeal, thereby possibly interfering with learning. In Keller's study, and in many since, students felt a greater sense of accomplishment, autonomy, and satisfaction from the PSI approach than they were accustomed to in traditional classes. Additionally, an improved grade distribution over the control group showed that the students had learned the course material more thoroughly than their traditionally taught counterparts. While popularity of PSI approach waned in the 1990s, modern advances in educational technology such as e learning have revitalized inquiry and interest into this and other models of self-paced learning (Eyre, 2007; Hambleton, Foster, & Richardson, 1998).

In a more recent study on the effectiveness of self-paced learning, Tullis and Benjamin (2011) found that students who had control over allocation of time spent studying particular material significantly outperformed those who had no control. The self-paced students were able to spend less time on topics that they felt were easier and more time on those they found to be more difficult, while still completing the overall course in the same amount of time. This success, however, was believed to be contingent on the students using an appropriate allotment strategy, likely attained through metacognition. This study reiterates the importance of the individual's understanding of how he or she thinks and acquires knowledge and understanding, and makes the case for increased emphasis on metacognition in a constructivist educational environment (Pritchard, 2014).

The previous two examples held overall course time constant, while allowing the individual to progress through the material at their own pace, according to aptitude and prior knowledge. All students would still finish the course at the same time, although having spent individually varying amounts of time on course concepts or modules. At the Center for Naval Analyses, Carey, Reese, Lopez, Shuford, & Wills (2007) studied computer-based self-paced courses in Navy initial technical training (A-School) programs to determine their effect on overall time to train. Their findings revealed a 10 to 30 percent reduction in training time, for which implications of cost savings are significant. This result is also consistent with Fletcher's (2010) Rule of Thirds regarding

reduced training time, reduced cost, and improved outcome for technology-based learning. According to Fletcher, time savings is the most consistent positive result of these types of individualized approaches to learning.

c. *Affection and Learning*

The third category of Corno and Snow's (1986) aptitude variables is affection, which covers attributes such as achievement motivation, engagement, and other personality characteristics. These variables tend to have a direct impact on a student's level of effort and ultimately, academic achievement. The Center on Education Policy, in a review of several types of technology-based educational media, such as video games and interactive and social technology tools, found that students' engagement with content and motivation to learn increased when these tools were introduced to the classroom (Usher, 2012). Hattie (1999) demonstrated in a meta-analysis of educational interventions, that a student's disposition toward learning, or academic motivation, did indeed have a significant effect on student achievement, at .61 standard deviations above the mean, whereas a .5 standard deviation improvement would approximate one letter grade higher on an exam. While the underlying mechanisms for changes in human affective states may not be fully understood or agreed upon by the academic community, it is clear that emotion does play an important part in the mixture of aptitude variables and their prediction of learner achievement (Cole, Harris, & Field, 2004; Corno & Snow, 1986).

C. BENEFITS OF PERSONALIZED LEARNING

1. Cost Savings

In addition to vastly improved learning outcomes, PL may also lead to greater efficiencies and cost savings in the training process. Evidence has shown that technology-based learning can affordably enable PL systems, and that these systems are not only more effective, but also more adaptable and more flexible than traditional models. As a result, a "Rule of Thirds" can be used to estimate the effects of technology-based learning. The rule states that, in general, these applications will lower the cost of instruction by approximately one-third, *and*, either time-to-train will be reduced by one-

third, or the knowledge and skills gained will increase by one-third, while time remains the same (Fletcher, 2010).

This finding has enormous implications for an organization the size of DOD, whose success absolutely depends on training and education, both in the classroom and in the field, where maintaining operational readiness and developing leaders and tactical experts is an ongoing priority. As such, the costs of dedicated "schoolhouse" training and education among the services account for approximately $8.7 billion per year (Department of Defense [DOD], 2015). This number is said to rise to upwards of $50B per year when all reservists, DOD civilians, and dependents are considered, along with other learning activities not specifically accounted for in the Operation & Maintenance (O&M) budget (Fletcher, 2011). In recent years, fiscal austerity has caused increased pressure to find ways to save on these vital, yet expensive requirements. For example, RAND Corporation studied PL (the Air Force calls it customized learning) opportunities for the Air Force with the sole intent of reducing time-to-train, and thereby significantly reducing costs (Manacapilli, O'Connell, & Benard, 2011). An improvement in the learning enterprise as a whole could free up additional resources to invest in operations, modernization of equipment, or other programs vital to national defense.

2.   Modernized Skillset

Another potential benefit of technology-based PL is a workforce better equipped to thrive in the technology-rich world of today. It must be recognized that skills required of the prototypical worker have evolved over time. In the transition from an industrial society, to a knowledge based one, cognitive skills, such as critical thinking, problem solving, creativity, and interpersonal communication have widely displaced requirements for manual labor (Woolf, Lane, Chaudhri, & Kolodner, 2013). Additionally, the rapid advance of technology necessitates a new kind of agile thinking and adaptability that the current system of education was not designed to address. Many learners today must endure passive, lecture-based instruction, absent of collaboration, critical thinking, and deep understanding. Automation of physical labor and proliferation of ICT will lead to structural unemployment for those not equipped to adapt their skillsets to new vocations.

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Technology-based PL can bring educational practices into the 21st century, ensuring that students are well prepared for the new challenges they will face in a technology-heavy, information dependent labor market. This sentiment applies equally to military members, if not more so. Our military's competitive advantage is increasingly tied to technological dominance, and skills required of our service members are heavily weighted in the cognitive domain (Fletcher, 2010). Maintaining operational adaptability in complex environments is paramount, and a system of learning that engages the active learner, encourages critical thinking, and requires demonstration of mastery before advancement is the key to defeating current and future adversaries (Department of the Army, 2011).

D. CASE STUDIES

1. Teach to One

The School of One program was initiated in 2009 in New York City middle school, and in 2012, renamed Teach to One, and further expanded to include 15 schools in several urban districts on the east coast (U.S. Department of Education, 2010). The program used varying technology-based delivery modes, daily assessments, and self-paced learning to teach math to nearly 6,000 academically and demographically underprivileged students in grades five through eight. A lesson bank, containing over 1,000 lessons, could be accessed in a tailored manner to learn 77 common math skills. Students' results on a standardized test, taken at the beginning and end of the school year, were compared to the national average to measure effectiveness of the program. Although the test group students began the school year significantly behind the national average, roughly .50 standard deviations, by the end of the second full year of operation, students had achieved results of .37 standard deviations above the national mean. In other words, Teach to One students showed improvements over the school year at a rate 47 percent higher than the national average gains (Ready, 2014). Using student inputs to establish preferred delivery mode, continuous assessments to determine level of competency, and self-pacing, the Teach to One program is an encouraging success story

for PL in a K-12 setting, and is currently expanding to more schools nationwide for further development and testing.

2. Continued Progress

In a similar study, RAND Corporation, in partnership with the Bill and Melinda Gates Foundation, evaluated 62 K-12 schools that had implemented a wide variety of PL approaches (Pane, Steiner, Baird, & Hamilton, 2015). While no standard methods of PL were imposed on the schools, a framework of five strategies was common across the group: learner profiles to understand individual differences, personal learning paths to allow student control, competency-based progression for self-paced achievement, flexible learning environments to enable a multi-modal instruction, and emphasis on college and workforce preparedness. The overall effect size found across the 62 study schools was .19 in reading and .27 in math. While this is a statistically positive result, it falls short of Hattie's (1999) average intervention effect of .40 standard deviations, suggesting that there are other, more effective approaches that might have been implemented. Of course, until the costs of all such programs are weighed along with these benefits, we must reserve judgment as to their relative values. Additionally, because the PL practices varied so widely across the schools, it is impossible to determine whether any specific approach types or particular use of technology had a more positive or negative effect, potentially skewing the overall result. One important qualitative observation from the study was the general lack of adoption of true self-pacing and competency-based advancement, in part due to pressure to maintain traditional grade-level structure and content in order to meet externally controlled standardized test requirements (Pane et al., 2015). This statement highlights outdated policies and organizational norms, which pose major barriers to implementing effective PL systems in any traditional educational environment.

3. Project RED

Project RED was a large-scale research effort across 997 K-12 schools in 49 states that began in 2010 with the aim of discovering how educational technology, particularly computer access for every student, might improve learning outcomes while remaining cost effective (Greaves, Hayes, Wilson, Gielniak, & Peterson, 2012). The

study found that technology, when properly implemented, improved learning outcomes while saving money for the schools. High-stakes test scores and graduation rates were significantly higher, while dropout rates and disciplinary actions were lower when the ratio of students to computers was 1:1. The greatest returns were realized when the technology was fully integrated into curricula and used on a daily basis. The authors also found that school administrators' leadership and support were critical to the success of any implementation effort. Although this program did not claim PL as its primary objective, the authors did feel that individualized instruction was the most significant reason for integrating technology into education:

> Individualized instruction is perhaps the most important use model of technology in education. Whether advanced or remedial, individualized instruction allows students to learn at their own pace and engage in learning at exactly the right entry point. Technology-based learning solutions provide almost limitless opportunities for personalization. If one approach is not working for a student, alternatives can easily be tried that are better suited to a student's individual learning style or experiences. Because students are in active control of their learning, they are more likely to stay on task. (Greaves et al., 2012, p. 16)

Though Project RED, and the other similar programs discussed have been focused on K-12 education, there is considerable evidence that PL does have potential meaningful benefits. If properly implemented with the right technology and with buy-in at all levels, PL has the power to transform the notion of education, as we know it.

E.   CHAPTER SUMMARY

Individualized approaches to teaching and learning can be traced to the very origins of formalized education, more than two thousand years ago. Though it has long been understood that a one-on-one relationship between teacher and pupil is optimal for learning success, the model is generally not scalable, and has succumbed over time to more cost-efficient methodologies. As technology advances and scientific understanding of how we think and learn has grown, so has an interest in reviving the concept of PL. Technology-enabled PL promises not only to improve learning outcomes by matching teaching strategies, methods, and timing to individual student differences, but it seeks to do so more affordably than traditional classroom learning. Thus far, the evidence is

mixed, but efforts to empirically show that PL is more effective, and that it can capture the two-sigma difference made famous by Bloom, continue in earnest. As cases of PL's successful implementation begin to accrue, educators and policy makers have recognized that a paradigm shift may be necessary for our education system to keep pace with changing times.

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III. TECHNOLOGY TO ENABLE PERSONALIZED LEARNING

One of the core propositions of this paper is that technology can be leveraged for PL in order to enhance the effectiveness of military training and education. The science behind how we think and learn has advanced in recent years, and technology is the key to capitalizing on that knowledge in ways not previously possible. However, we should not assume that more is better, nor use technology for technology's sake. The pedagogy must be considered first, followed by the *right* technology as a tool to enable the desired educational approach (Oblinger & Oblinger, 2005). The U.S. Department of Education emphasized the impact of technology in learning in the 2010 National Educational Technology Plan:

> Just as technology is at the core of virtually every aspect of our daily lives and work, we must leverage it to provide engaging and powerful learning experiences, content, and resources and assessments that measure student achievement in more complete, authentic, and meaningful ways. Tech-based learning and assessment systems will be pivotal in improving student learning and generating data that can be used to continuously improve the education system at all levels. (U.S. Department of Education, 2010, p. v)

When properly implemented, these tools have the power to maximize student potential, capturing the benefits of one-to-one tutoring that Bloom (1984) articulated. Two other factors that technology can enhance are flexibility and responsiveness. Flexibility refers to place and time, bringing the instruction to the point of need at precisely the time that it is needed. The Navy's Ready Relevant Learning initiative seeks to accomplish this by leveraging technology to re-engineer technical training course content, delivery schedule, and delivery modes in order to better match training with the needs of Sailors (Department of the Navy, 2016a). PL technologies that are responsive, that can adjust real-time to the learner's preferred style or speed, prior knowledge, and aptitudes, can ensure that all students reach their maximum potential with no time wasted and often at a cost savings (Dede, 2013).

This emphasis on both effectiveness *and* efficiency is particularly resonant within DOD, which must train and educate more than 2 million active and reserve service

members and 800,000 civilians (per defense.gov), at a cost of more than $6.5 billion annually (DOD, 2015). Since the 1950s, the department has invested heavily in the research and development of education and training technology, and is largely responsible for innovations such as computer-assisted instruction (CAI) and computer-based simulation (Fletcher, 2009). DOD has continued to pursue technological solutions such as Interactive Multimedia Instruction (IMI), Advanced Distributed Learning (ADL), and Intelligent Tutoring Systems (ITS), in order to maximize both the effectiveness and efficiency of its education and training enterprise (DOD, 2001b; Fletcher, 2010). In the following section, I will discuss these and other programs, systems and models that seek to do just that.

A.   TYPES OF TECHNOLOGY-BASED INSTRUCTION

1.   DOD-Interactive Multimedia Instruction (IMI)

Interactive Multimedia Instruction (IMI) is a broad term used to describe a variety of interactive, electronically delivered software tools for instruction, as well as for training management and support. IMI technologies include: interactive courseware (ICW), electronic maintenance publications (e-pubs) and other job aids, learning management systems (LMS), simulator trainers, and web-based products for Advanced Distributed Learning (ADL). These systems can be used to flexibly deliver interactive, competency-based, and individualized multimedia instruction. IMI are intended to capitalize on the multimedia effect, varying delivery modes during instruction in order to accommodate differing preferences and predispositions in the maximum number of students. Research shows that this can be done with success, having shown an average effect size of .50 standard deviations (Fletcher, 2010).

According to DOD (2001b), IMI should be considered when a large number of students are dispersed over time and place, or when students vary in experience or skill level. This prescriptive statement describes nearly every imaginable setting for training and education within the Navy. Additionally, IMI can be designed for use in multiple levels of instruction, which could considerably decrease overall life cycle costs due to economies of scale. However, an IMI system with more comprehensive content would

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certainly be more costly to develop. An in-depth cost-benefit analysis is a critical step in the process to design and implement a technology to replace legacy systems and methods of instruction.

2. Advanced Distributed Learning

First introduced by DOD in 1997, the purpose of the Advanced Distributed Learning (ADL) initiative was to leverage computer technology to develop and distribute personalized, cost-effective, always available, high quality training and education to service members and DOD civilians (Wisher & Fletcher, 2004). The need for ADL developed from the understanding that interactive, engaging, and learner-centric approaches to education were likely far more effective than the traditional instructor-led model, and from the recognition that ICT was sufficiently advanced and ubiquitous to capitalize on this new knowledge.

> The advanced distributed learning strategy requires re-engineering the learning paradigm from a "classroom-centric" model to an increasingly "learner-centric" model, and re-engineering the learning business process from a "factory model" (involving mainly large education and training institutions) to a more network-centric "information-age model" which incorporates anytime-anywhere learning. (DOD, 2000, p. 9)

Figure 2 depicts a vision of this information-age model, showing how ADL could be implemented to achieve unprecedented access to high-quality learning content.
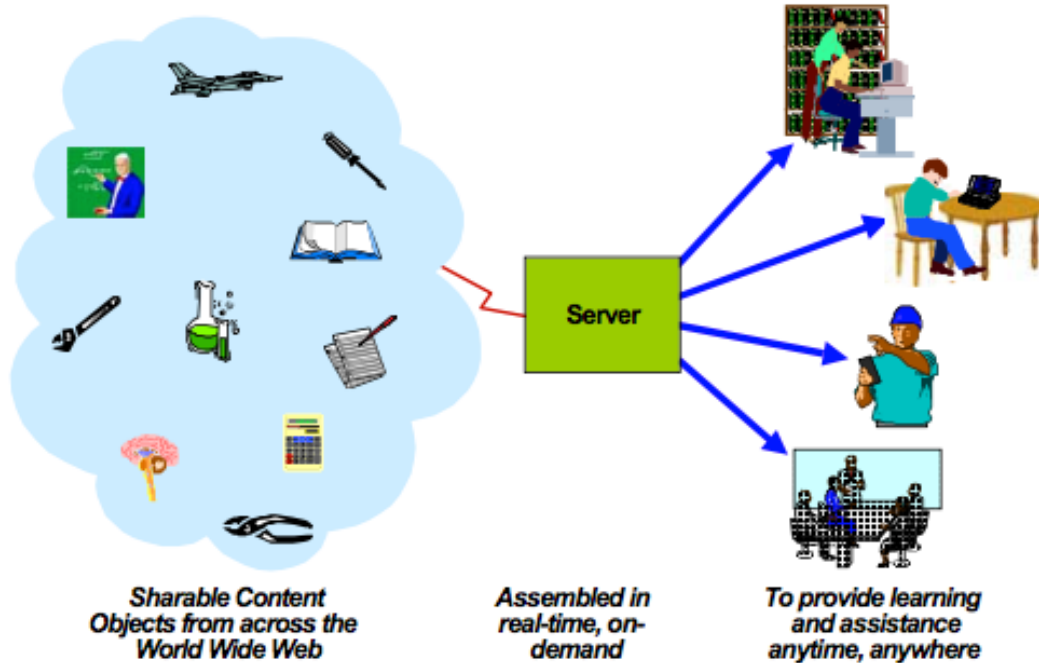
Figure 2. Theoretical Network Architecture for ADL. Source:
Wisher & Fletcher (2004).

3. Intelligent Tutoring Systems

Computer-assisted instruction and computer-based training, the foundational technologies for ADL, are systems that deliver and manage educational content through the use of computers, usually in a multimedia format. Given today's proliferation of ICT, this definition includes essentially any form of technology-based educational tool. The underlying "intelligence" of these systems, however, varies widely across four general categories of CAI: drill and practice, tutorial, tutorial simulation, and tutorial dialogue. Though all of these types of CAI can be individualized to pace, content, sequence or style, only tutorial dialogue attempts to explicitly integrate the attributes or qualities of a one-on-one teacher to student relationship (Fletcher, 1992b, 2010). These computer-assisted instruction programs are commonly referred to as Intelligent Tutoring Systems (ITS) and typically incorporate elements of artificial intelligence (AI) and machine learning to facilitate the understanding of student level of knowledge, response to individual needs, and teaching based on learning style or preferences, all in real time.

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Another goal of ITS is to enable mixed initiative dialogue, or the ability of the system to carry on a natural, free form conversation with the student (Woolf et al., 2013). One analysis of a group of recent ITS showed an average effect size of 1.05 standard deviations, showing potential to meet the two sigma benchmark as the technology progresses (Fletcher, 2010). With the exception of education, AI has proliferated through most industries, enhancing growth and productivity. Although AI-enabled ITS are currently capable of tailoring learning to individual needs, they are not yet widely used.

Although ITS have been in development since the early 1980s, exponential advances in computing power have enabled recent breakthroughs in AI, a primary component of modern ITS (McArthur, Lewis, & Bishay, 2005). Today's intelligent learning systems can understand a student's thought processes, motivations, emotions, and even metacognition, essentially creating a mentor for every learner. Machine learning and data mining techniques also support this understanding of students and how they learn (Woolf et al., 2013).

ITS are generally comprised of five basic components, as shown in Figure 3: a student model, pedagogical module, domain knowledge module, expert model, and communication module or interface. The student model creates a unique profile based on information gathered from the individual learner. This component tracks the student's progress by measuring changes in learning, which allows the pedagogical model to adapt instruction to the student, whether in timing, content, or delivery method. The pedagogical model makes decisions on how to teach, according to data collected by the student model. The domain knowledge module contains and manages a representation of all facts, concepts, and mental models of the information that is being taught. The expert model compares the learner's responses to the "ideal" student's correct solution and recommends any required remediation. Finally, a communication module controls all interactions with the student through a user interface. This component includes visual layout and presentation of material, as well as dialogue between the student and the system, whether textual or voice. Throughout the learning process, the first four elements are in constant communication with one another. These interactions happen at machine speed, keeping the student engaged in real-time via the communication module. Without

timely, continuous, and meaningful feedback to the user, the true value of an ITS may go unrealized (McArthur et al., 2005; Woolf et al., 2013).
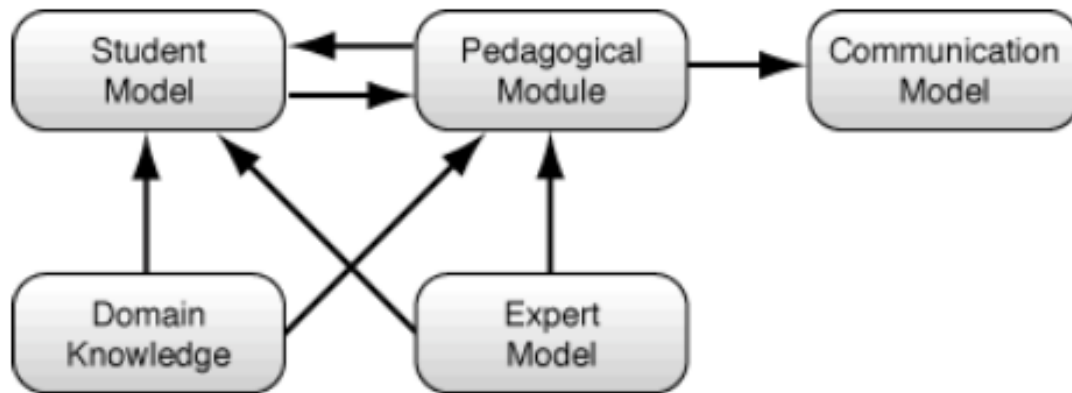

Figure 3. Components of an Intelligent Tutoring System (ITS). Source: Beck, Stern, & Haugsjaa (1996).

Because of their inherent complexity and the need for such in-depth representation of the knowledge contained within, development time and costs are major limitations of ITS. Estimates as high as 200 man-hours of construction time per one hour of instruction highlight the requirement for significant upfront investments to develop an ITS (Fletcher, 2010). While the savings in delivery costs once the system is in place can quickly offset development costs, the time horizon to realize enough economies of scale to warrant purchase of the ITS must be determined on a case by case basis. Clearly, there is a need for innovations in software development to mitigate potentially prohibitive costs of constructing an ITS. Two possible solutions to the problem are common authoring tools, and modularity. Authoring tools would allow a standardized, straightforward development platform, which could allow a wider range of users the ability to create and edit their own courseware. A system of modular ITS components, created using a common protocol, would allow reuse between systems and developers, greatly reducing time to author each new application. These "off-the-shelf" modules could be fit together as needed to create a combination unique to each specific use, without the need to build each section from the ground up (Beck et al., 1996).

4. Sharable Content Object Reference Model

In recognition of these limitations, the ADL initiative's goal is to create learning systems that are interoperable, reusable, and affordable. As such, they have directed the creation of a common architecture and set of standards for use in building ITS and supporting elements. The Sharable Content Object Reference Model (SCORM) was developed to enable learning material and ITS components to be shared across various instructional delivery settings. SCORM is an important first step in the adoption of an industry-common format for ITS, and the ADL program's continuing research efforts and collaboration with government agencies, industry, and academia seek to make that a reality (DOD, 2001a; Wisher & Fletcher, 2004).

5. Learning Management Systems

A learning management system (LMS), the backbone of any distributed learning system, is a server-based middleware that controls delivery of content, gathers data, and tracks students' progress within the course of study (Wisher & Fletcher, 2004). The LMS is a critical component of ADL's vision of future education and serves to connect the learner to instructional programs and content, anytime and anywhere. An LMS also allows oversight by administrators and developers to keep course content current and to track and repair malfunctions in the software. The LMS communicates directly with course management system (CMS), which serves as the program's interface with students. The CMS launches the course, tracks progress, and provides feedback to the student. The CMS often is fully integrated within an ITS, and multiple ITS may report to a single LMS for overall management of a unit's training and education program (DOD, 2001a; Wisher & Fletcher, 2004).

6. Digital Teaching Platform

A Digital Teaching Platform (DTP) is an approach to technology infrastructure that incorporates interactive teaching and personalized learning technologies into a traditional classroom setting. DTP is based around a networked digital environment, where every student and the teacher have computing devices. However, whereas ITS seem to imply an individually guided effort, the DTP emphasizes the teacher's key role

as facilitator and administrator of learning. Many software solutions aim to make the teacher obsolete, but DTP supports current infrastructure and classroom paradigms, perhaps easing the transition to an all-digitally moderated learning environment in the future (Dede & Richards, 2013). The classroom work dynamic is flexible with DTP, allowing for both individual and group work, whether synchronous or asynchronous. This ensures the ability to reinforce a social constructivist theory of learning, and aligns with the common assertion that millennials tend to prefer working in groups to isolation and individual effort (Dede, 2005; Oblinger & Oblinger, 2005).

Differing from an LMS where the software manages a majority of functions, DTP keeps the teacher at the center of the evolution, responsible for curriculum planning, student learning progress assessment and remediation management (Dede, 2011). The teacher's ability to monitor engagement and interest, to foster relationships with students, and to prescribe interventions as needed, along with the technology's ability to personalize instruction in real time, give timely and meaningful feedback, and enable competency-based progression through adaptive computer-proctored assessments are a combination which can have synergistic effects in the classroom. Students are able to use technology to which they are accustomed in their daily lives, collaborate and interact with peers, and still receive individual support from the teacher in an as-needed, focused manner (Dede & Richards, 2013). DTP is a hybrid approach to changing the paradigm of learning for the 21st century. It aims to capitalize on advances in ICT and PL to improve learning outcomes, even in the face of budget cuts and overcrowding, while retaining the inherent social and structural benefits of instructor-led classroom environments.

7.   Synthetic Learning Environments

A synthetic learning environment (SLE) replaces or augments a real-world interaction within the context of a computer-based game, simulation, or virtual-world experience. The ideal SLE applies pedagogical principles along with accounting for individual learner differences to deliver an optimal experience for learning (Cannon-Bowers & Bowers, 2008). Games and simulators have long been used as training devices, with varying degrees of sophistication and emphasis on sound pedagogical approaches.

Incorporation of these legacy tools, along with budding virtual world technologies such as virtual and augmented reality, are allowing SLE to become legitimate alternatives to traditional educational models. Vogel et al. (2006), in a meta-analysis of educational interactive simulation and computer game research, found that these tools did significantly improve learning outcomes over conventional teaching methods.

Several factors seem to impact effectiveness of SLE, and among these are level of immersion and the theory of situated learning. Immersion, or presence, is the sense or level of belief that one actually inhabits a simulated event or place. Higher levels of immersion are linked to increased engagement and information retention; however, the user's spatial ability may be an important moderator in this effect. Although most SLE can be easily tailored to the specific needs of the learner, those that are not visually oriented, or who are not as comfortable with immersion may not be inclined to use SLE, or may do so with poor results (Cannon-Bowers & Bowers, 2008). Virtual and Augmented reality are forms of SLE that provide the highest levels of immersion.

Situated learning theory, with roots in constructivism, is based on active participation in rich contextual scenarios, guided and assessed by an expert mentor (Pritchard, 2014). Learning occurs by completing authentic learning tasks, so named because they take place in a realistic environment, under realistic conditions, and with active guidance from the mentor. Learners are more likely to engage at a deeper level through authentic tasks within the appropriate context, than inauthentic tasks in the wrong context (or none at all), such as a traditional classroom. This approach to learning in essence takes Bloom's one-on-one tutorial relationship to the next level by placing the instruction in context, in a situated environment. This concept has familiar underpinnings in the world of simulation, where fidelity of the experience, both physical and psychological, are critical to the level of transfer achieved by the trainee (Cannon-Bowers & Bowers, 2008). Transfer, or the ability to apply in the real world what is learned in a training environment, is maximized using experience-based, engaging, and context-correct instructional methods such as situated learning (Dede, 2005).

Virtual humans, able to replicate the speech patterns, mannerisms, and affectations of humans, are an advanced interface used for creating social interactions and

improving presence within a SLE. Virtual humans use advanced modeling and graphical representation of human movements, artificial intelligence, speech recognition, and natural language processing to create very believable pedagogical agents. These intelligent agents can enhance student engagement with learning material by creating rapport, inciting enthusiasm or motivation, or encouraging a struggling student. In fact, people tend to interact with virtual humans much the same as in human-human engagements (Swartout et al., 2013). While accommodating the desire for social contact by learners, virtual humans can add to the contextual realism and effectiveness of SLE. AI-enhanced virtual humans have the potential to become the mentor for every student, closing or even surpassing the two-sigma gap, and are an exciting development to monitor as research continues.

While highly immersive, SLE inhabited by virtual humans is another tool and not a panacea; they have many interesting and potentially impactful benefits for training and education. These context-rich, highly adaptable platforms make them a natural fit for PL. Although an SLE breaks the mold of traditional school settings, perhaps eventually rendering it all obsolete, it does not imply that the teacher goes away, or that there's no social interaction between peers. In a virtual world, these ideals would simply take on a very different meaning.

B.   CHALLENGES AND OPPORTUNITIES

Many of these technological solutions are ripe for widespread adoption, but there are challenges to implementing them into the current training and education enterprise. One important implication is the changing role of the teacher that would occur when shifting to a learner-centered paradigm. PL, by nature, is typically self-regulated and computer moderated. Once considered a "'sage on the sage," or primarily a transmitter of knowledge, the instructor would become "guide on the side," as more of a facilitator or mentor for PL, and allowing the technology to take on many of the mundane or time-intensive course management tasks, such as creating and individualizing learning plans to students' needs and administering regular diagnostic assessments of their progress (Dede, 2013). In a new role as mentor or coach, instructors could better utilize their expertise in

the subject matter to provide context for students and foster dialogue, placing less emphasis on teaching skills and background in education. This point is particularly salient for the military environment, where service members are given instructional duties based on operational or technical experience, not on teaching credentials, and training time for instructional techniques is limited (Manacapilli et al., 2011).

Another challenge is the risk of disruption of current established educational norms and economics in schools (Dede, 2013). Some techniques, such as DTP, promise to seamlessly integrate into today's classrooms, but nearly all technology-based learning approaches call into question the need for schools' continued existence in their current form. Doing away with the traditional classroom and standard school day raises cultural and political barriers to acceptance. Although we now have all the means necessary to implement effective PL models on a large scale, massive reforms and reorganizations would be required. The implications of upending the traditional paradigms for learning are significant and not fully known. For these reasons, organizations should adopt an incremental approach to incorporating technological solutions into training and education programs, and only those solutions that are built upon a sound pedagogical foundation with proven results.

C.   CHAPTER SUMMARY

Taking all of these challenges into consideration, we can draw some useful conclusions about what is required for successful implementation of technology-enabled PL programs. First, the technology is simply a resource that allows the learner-centered, tutorial instruction to become affordable and viable (Grant & Basye, 2014). It erases the economic impossibility. Next, the tech enables continuous formative assessments throughout the learning process, so that teachers (or the program itself) may address student limitations and capitalize on strengths in a timely fashion (Grant & Basye, 2014). That being said, the teacher's role must adjust from transmitter of knowledge to facilitator of learning, following a constructivist theory.

The learner's progression through a PL program should be competency-based, with self-paced advancement occurring only after demonstrating mastery of the material.

This progression is achieved by providing instruction in a manner best suited to both the subject matter and to the individual preferences of the learner. Finally, the learning environment should be malleable, facilitating important social interactions between peers and with the mentor, while enabling individual progress through the content (Grant & Basye, 2014). In a fully integrated, yet supporting role, the technological solutions outlined in this chapter stand ready to offer new and more efficient ways for students to receive and interact with educational material, optimizing every student's performance through personalized learning.

IV.   METHODOLOGY: COST ANALYSIS

In this chapter, I present the different types of cost studies that may be used to analyze a PL program, and illustrate how cost-effectiveness analysis is particularly suited to this type of problem. I will also introduce a theoretical model of the costs of human tutoring, lecture-based classroom instruction, and technology-based PL approaches to learning, with the intent of highlighting the differences in learning approaches in terms of fixed, variable, and marginal costs. Finally, I will discuss methods of determining the costs and benefits of educational programs for comparison in a cost-effectiveness analysis.

A.   COST STUDIES

Cost studies combine an objective and quantitative determination of program effects with a thorough and detailed evaluation of costs, based on sound economic principles. Benefits, or effects on outcome, are compared with costs through a variety of methods to arrive at a net benefit or some other measure of value. These analyses may be used for a variety of purposes, such as comparison of multiple courses of action, identifying areas for improvement, expansion of academic understanding, or for ensuring adherence to policy requirements (Ross, Barkaoui, & Scott, 2007). Although there are many frameworks and methodologies used for conducting cost studies, they all have a common general flow: determine the objectives of the study and alternatives (if any) to be compared, decide on the method of analysis, measure or calculate all applicable costs and benefits, compare the costs and benefits to find the net benefit, perform a sensitivity analysis on the results, and recommend a course of action. The most commonly used types of cost study for educational evaluation are cost-benefit analysis (CBA) and cost-effectiveness analysis. The primary distinction between the two is that a CBA evaluates costs and benefits converted into common units, usually monetary, while a cost-effectiveness analysis typically compares non-monetary benefits to monetary costs (Ross et al., 2007).

When measuring the costs and benefits of a multi-year program, the time value of money must be considered. This process recognizes there may be inflation and applies a discount rate to future costs and benefits. The net present value (NPV) is the parameter of interest, as it expresses all current and future costs and benefits in present day dollars so that programs can be compared side by side. Additionally, a sensitivity analysis should be completed on all parameters to determine robustness of findings. This is easily done with a model, as any change to one element will propagate throughout. Sensitivity analysis also helps to highlight the primary cost drivers, which further aids in decision making. Finally, while no approach to cost study is perfect, any known limitations of the model and assumptions made must be explicitly stated at the outset.

B.   TYPES OF COST STUDIES

In order to make a direct comparison between costs and benefits, a CBA first converts the two into monetary units. From here, a few levels of analysis are possible. First, the benefit/cost ratio can be calculated by dividing the overall value of the result by the overall cost. Alternatively, return on investment (ROI) may be expressed as a ratio of net benefits (total value minus total costs) to costs. Although a result of greater than one indicates positive outcome using either metric, ROI may be preferred because it more easily aligns with other financial reporting criteria. However, there may be variations using either method depending on the cost model used, assumptions made in converting units, and time value of money rates (Fletcher & Sottilare, 2014). Therefore, a cost-effectiveness analysis may provide a clearer understanding of the true cost-benefit relationship of an educational program, whose effectiveness is often difficult to monetize (Fletcher, 1992a).

One important distinction to make in a cost-effectiveness analysis is whether the desired outcome is to reduce time to train (cost), while keeping learning objectives constant (effectiveness), or to improve learning outcomes, keeping time constant. With continuous pressure on maintaining both fiscal accountability and operational readiness, military and government organizations nearly always seek the former outcome (Fletcher & Sottilare, 2014). Evaluating cost-effectiveness for multiple educational systems is

accomplished by: comparing a ratio of total cost to effect size, minimizing cost to show any improvement in effect size, or maximizing effect size without regard to cost. No standard decision rule criteria exists for technology-enabled PL systems, but in general, a program is worth adopting if it demonstrates: greater effectiveness for the same cost than the alternatives or status quo, the same effectiveness at lower cost, or the highest cost-effectiveness ratio (Ross et al., 2007). The decision space for comparing a single program to the status quo is depicted in Table 1, with question marks indicating an ambiguous result and need for further analysis. Of note, the sequence of measuring effectiveness and costs of a program is important, as a decrease in effectiveness from the status quo requires rejection without need to spend time and resources calculating the program's full costs (Fletcher & Sottilare, 2014).

Table 1.   Decision Space for Cost-Effectiveness Assessment. Source: Fletcher & Sottilare (2014).

		Costs	
		Increase	Decrease
Effectiveness	Increase	??	Accept
	Decrease	Reject	??

C.   DETERMINING COST OF INSTRUCTIONAL PROGRAMS

Overall cost calculations for instructional programs can fluctuate greatly based on what assumptions are made and the processes used to ascertain and measure all cost components (Fletcher, 1992a). These assumptions and procedures must be explicit in any evaluation. To organize and define all cost elements, Fletcher (1992a) recommends starting with an accepted framework of cost components, such as the Knapp and Orlansky model (1983). This model breaks down the main elements of life-cycle costs (LCC), R&D, initial investment, operations and maintenance, and disposal, further into their hypothetical supporting elements. Although the model contains 75 separate cost components, not all are relevant or applicable to instructional systems. For instance,

R&D and initial investment costs are likely sunk for an existing program and wouldn't be included. Likewise, disposal and salvage costs are typically minor for instructional systems and often omitted from analysis (Fletcher & Sottilare, 2014).

Fletcher and Sottilare (2014) developed another useful model for classifying training and education costs based on earlier work by Levin (1983) and Kearsley (1982). The framework uses six cost categories: personnel, facilities, equipment, consumables, other direct costs, and indirect costs. Personnel costs include any human resources required to administer the program, while facilities costs refer to the physical space used. Equipment includes the instructional materials, software, and other physical furnishings, and consumables are items that are used up, such as office supplies. Other direct costs, including client inputs, would include opportunity costs incurred by the student or employer. For example, in a military setting, this category would include the student's pay and benefits paid by the sponsor organization during training, also a primary cost driver (Angier & Fletcher, 1992). Indirect costs covers shared operating costs, administrative expenses, and overhead, and these costs may be characterized as fixed, variable, or mixed. The six cost categories can be further organized across the temporal phases of instructional systems development: analysis, design, development, implementation, and evaluation, creating 30 separate "bins" (Fletcher & Sottilare, 2014).

Using one of above two frameworks for cost analysis, the educational evaluator or economist can readily identify, classify, and then analyze all parts of the cost side in a logical, coherent manner. While this analysis may be thorough, and may accurately compare a PL program with the status quo, it gives us little indication as to the relationships and differences between cost components within each model as a whole. Understanding how the cost curves behave can give the decision maker a clearer idea of the potential long-term benefits of a technology-based PL approach.

D.   THEORETICAL MODEL

Analyzing the relationship between cost components, such as fixed, variable, average total, and marginal costs provides another perspective for understanding the differences between human-tutoring, teacher-led classrooms, and technology-enabled

personalized learning. Economies and diseconomies of scale become more apparent, as do the differences in unit costs of education. Also, we can better illustrate the benefits provided by PL, by describing each student's effective learning level as a marginal benefit. This basic microeconomic assessment of cost curves is intended to serve as a theoretical model for comparing and contrasting the cost behavior of differing approaches to instruction.

Beginning with the oldest and most straightforward approach, the Aristotle model assumes that a single teacher is assigned to every student. There are very low fixed costs, as this one-to-one tutoring doesn't necessarily require a classroom or high-tech instructional materials. The major cost is the teacher's compensation, which is variable, so that with every additional student trained, the organization must pay another full salary. The average total cost curve is flat, and relatively high, showing no economies of scale. However, the marginal benefit remains relatively constant, as every student gets a teacher full-time. As these are human teachers with differing levels of skill and knowledge, this curve the marginal benefit is likely different for each student. As long as the marginal benefit exceeded the marginal cost, and there were no constraints on the budget, this approach would make sense to implement.

The industrial model, or teacher-led classroom approach, is next. Fixed costs are generally comprised of school buildings, furniture and instructional equipment. This fixed cost curve is stepped; when enough students are added to require expansion, you need a bigger school, more classrooms, more equipment, etc. The curve is flat again until the school reaches capacity. Curriculum has already been developed and is a sunk cost. Variable costs of students can be significant, including cost of travel to the school, extra TAD pay, lodging, and materials and other expenses. Variable costs of instructors will behave in a stepped manner, as more teachers are needed when enough students are added to require an additional classroom.

While there are small economies of scale initially and after each classroom/teacher addition, we likely see constant return to scale. However, one could imagine that diseconomies of scale to arise when the school is so large and overcrowded that it struggles to operate efficiently, requiring additional infrastructure and

administrative investments. Variable costs are a primary driver of total costs, which increase rapidly with student population. Benefits start at the same level as the previous one-to-one model, but as students are added to a classroom, this benefit begins to decrease until the classroom reaches capacity and another classroom is added and another teacher hired. The marginal benefit will saw tooth with student to teacher ratio, but would likely not return to the beginning state of 1:1, reflecting the assumption that higher student-teacher ratios negatively affect learning outcomes.

Although PL can be, and has been applied directly to existing physical classrooms, its potential is better highlighted when applied via the ADL concept, where instruction is distributed to the point of need via virtual classrooms. Therefore, one notable absence from variable costs of the PL model would be travel and TAD expenses. While human mentors are still a part of PL, higher ratios would be acceptable, as the technology manages much of the administrative burden. Due to the network effects of economies of scale and distribution of instructional programs away from traditional schoolhouses, the high upfront development costs of an ITS are quickly diluted over increasing numbers of students, while distribution costs remain relatively stable, with only slight increases when extra servers, human mentors, or system administration cost steps are reached. The combined effect of network economies of scale and low delivery cost through distribution of learning lead to a very low marginal cost per student, and a long-term average total cost much lower than the industrial model.

The PL model captures all of the benefits of Aristotle model, but illustrates that a significant economy of scale exists when variable delivery costs are kept low. Although initial investment into PL is significant, often requiring as much as 200 man-hours and $50,000 to develop one hour of instruction, these economies of scale are best realized when PL is used to transform courses with longest lengths and highest throughput of students (Fletcher, 2010). All three models point out the critical concept that long-run average total costs are most sensitive to delivery of instruction, not content development or school infrastructure. Fewer human teachers, less travel time and cost, more cost-effective delivery of training, and a consistently high level of student performance make PL a seemingly attractive alternative to the industrial model, although candidate

programs should be analyzed on a case-by-case basis to determine individual viability before conversion.

E.   OPPORTUNITY COSTS

Opportunity cost refers those costs incurred or things that must be given up to acquire something, and they may either be easily measurable or more qualitative in nature. In terms of comparing instructional models, I will discuss what is given up by choosing the traditional lock-step classroom approach over technology-based PL, and vice versa. While not always readily apparent, study of these opportunity costs is a vital component of any comprehensive comparison of alternative programs.

Time savings is perhaps the most rigorously proven and highest payoff benefit for technology-based self-paced PL. With PL, faster completion rates result from pace, content, and sequence of instruction all being tailored to individual student needs. Compare this to the lock-step approach, which keeps groups of students together in time, location, and learning rate as a class. Carey et al. (2007) found that converting Navy initial technical training (A-school) courses to computerized self-paced format reduced time to train by 10–31 percent, and that performance in follow-on training was not adversely affected. Fletcher's (2010) continuing analysis has shown a conservative rule-of thumb being a 30 percent savings in training time for adopting technology-based instruction. A primary driver for cost of training is student pay and allowances, so reducing time to train has always been a goal of instructional systems developers. In order to determine the opportunity costs incurred due to longer time to train with traditional instruction, a rate for the daily 'cost of a Sailor', called the Individuals Account programming rate can be used. To calculate this cost, multiply the rate given for the current year (in 2007, it was $148/day) by the difference in days between the lengths of alternative programs (Carey et al., 2007). To maximize the effective savings from this opportunity cost, we should target courses with longer current length and higher student throughput for conversion to PL.

As PL solutions tend to be more portable and flexible than traditional learning, other potential savings occur when training is distributed to point of need, saving travel,

TAD, and lost work costs. Though less straightforward than time-to-train savings, these opportunity costs are also quantitative and easily calculated (Fletcher, 2010). Another, less apparent benefit of technology-based is the inherent ability for data collection compared to traditional models. This data enables a better understanding of the optimal amount of training needed for an individual, including how long that training should take (Angier & Fletcher, 1992). These insights can then be applied to further refine the courseware development process as PL approaches gain ubiquity. Technology-enabled, flexibly distributed PL is a force multiplier that enhances operational readiness, while maintaining or reducing personnel costs. Reducing time-to-train gets people back to work faster, thereby increasing readiness with same force size (Fletcher, 2010).

Adoption of self-paced learning approaches is not without opportunity costs. The traditional military classroom has some qualitative benefits that may be largely excluded from PL and are worthy of mention. For instance, students' exposure to experienced instructors and one another throughout a course affords additional time for military training, discipline, and camaraderie, which is especially critical early in a career (Fletcher, 2010). Team-building exercises, "sea stories," and experience-based contextual examples are natural elements of today's military classroom, but developers of PL will need to find new ways achieve these benefits. "Sailorization" is a process by which the Navy imbues culture, values, and traditions into its members and ensures a foundation for teamwork, pride and professionalism.   This, along with unit-cohesion and esprit de corps are intangible aspects of the naval service that are vital to success, and any PL initiative would need to be careful to maintain these attributes that a group of students would normally develop during training.

Another potential opportunity cost to implementing PL occurs when self-paced blocks of instruction are combined with lock-step modules. In these cases, the full benefits of PL are not likely to be realized, as faster learners must wait on slower learners in order to continue training. This creates a free resource problem, and the potential exists for negative outcomes (Angier & Fletcher, 1992). One solution would have early finishers of self-paced modules continue learning towards an even higher level of understanding. Alternatively, they may be allowed to undertake additional qualifications

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or be incentivized to assist in the progress of slower learners. This issue would need to be evaluated on a case-by-case basis early in the design process, when a simple reorganization of course structure might alleviate the problem altogether.

All of these opportunity costs represent tradeoffs that are likely to occur when deciding between alternative instructional approaches. Course designers and evaluators should be aware of these elements in order to measure and compare them, and also to incorporate new methods and techniques that could offset the costs. Tradeoffs are a part of any economic analysis, and must be fully acknowledged if the best decision is to be made.

F.   DETERMINING THE BENEFITS OF INSTRUCTIONAL PROGRAMS

The primary benefit of an instructional program is its level of effectiveness at achieving learning objectives. In this section, I will discuss two widely accepted methods for evaluating and comparing the effectiveness of these programs: effect size and the Kirkpatrick Model. Effect size is most commonly used to compare study results in the realm of education, while the Kirkpatrick Model has been primarily implemented in organizational training settings. While either method can easily adapt to either education or training evaluation, availability of data and the type activity being assessed will dictate which is chosen. Effect sizes are most readily derived from results of highly controlled, academically rigorous studies or experiments. The Kirkpatrick Model is designed to capture data from multiple perspectives, from staged experiments to real-world application of training. That said, there are aspects of each approach, which could even be mixed together, as the situation allows, reaching a more comprehensive assessment of program effectiveness.

1.   Effect Size

Across the academic literature, effect size is most often used to explain the results of a particular intervention as compared the status quo or to alternative interventions. This method is given so much leverage, that often, the simple finding of a statistically significant effect by a study that meets standards of rigor and control is evidence enough to prove a program worthwhile (Ross et al., 2007). While there are some inherent

problems with this singular emphasis, the concept is well rooted in the literature. Hattie's (1999) seminal work synthesized effect size data from 337 meta-analyses, covering 180,000 studies and 200,000 effect sizes to conclude the average effect of educational interventions and innovations to be .40 standard deviations. Along with Bloom's (1984) findings that one-to-one tutoring produced an outcome of 2.0 standard deviations above the mean, these benchmarks have helped shape the interpretations of effect size into the generally accepted standards shown in Table 2. Additionally, each range of effect sizes is explained in the table by the percentile increase for a theoretical student at the 50th percentile before the intervention. For example, an effect size of .5 is an improvement of a student from 50th percentile to 69th percentile, while an effect of 2.0 raises that student to the 98th percentile (Fletcher, 1992a).

Table 2.   Interpreting Effect Size of Educational Intervention Results.
Adapted from Fletcher & Morrison (2014).

Effect Size	Suggested Interpretation	50th Percentile Raised To (Est.)
< 0.25	Negligible	59th percentile
0.25 - 0.40	Small	60th-65th percentile
0.40 - 0.60	Moderate	66th-72nd percentile
0.60 - 0.80	Large	73rd-78th percentile
> 0.80	Very Large	79th percentile and up
> 2.00	1:1 Tutoring Benchmark	98th percentile and up

In order for an effect size to have any true meaning, the study by which it was found must be of a quality such that the findings can be trusted. The level of rigor and attention to appropriate methodology must be present in the research before evaluators rely on this metric for a cost-effectiveness analysis.

2. Kirkpatrick Model

Kirkpatrick's Four Levels Evaluation Model is another widely accepted method for evaluating the effectiveness of training for a variety of organizational types (Kirkpatrick & Kirkpatrick, 2006). The levels are: 1-Reaction, 2-Learning, 3-Behavior, and 4-Results, and are intended to be followed sequentially, beginning with reaction and continuing to results, as resources allow. Each successive level builds upon what has been learned in the previous steps. Reaction is the immediate post training assessment of student satisfaction, often recorded via survey. The learning level assesses the degree to which training objectives were achieved, or whether the student acquired the knowledge or skills intended. A post-training test on these objectives would be the simplest way to accomplish a Level 2 assessment. Level 3, behavior, refers to the application of learned knowledge or skills to the work environment. Knowing from Level 2 that the training was successful, Level 3 helps to determine if it is the right training for the job being performed, and how well the student has transferred training to performance. Behavior is more difficult to measure, and is often assessed through surveys, interviews, or observations of the worker and their supervisor. Finally, the results level seeks to determine whether the training and subsequent transfer of acquired knowledge and skill produces any tangible benefit to the organization. Results are often the most troublesome metrics to capture, as many organizations do not have the data tracking capability to determine causality of changes in productivity, and DOD is no exception.

G. CHAPTER SUMMARY

Measuring the benefits of technology-enabled PL programs is critical to an accurate cost-effectiveness analysis, and can be accomplished by using effect-size comparison or the Kirkpatrick Model, two tried and true techniques. While both methods are backed by decades of research and peer-reviewed publications, the onus remains on the evaluator to ensure that the data collected is done so in an academically rigorous manner. Biases and external influences should be recognized and controlled for whenever possible. In the end, the most important consideration is that the programs' results are being compared in like units and using the same methodologies.

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V.   DIGITAL TUTOR CASE STUDY

The U. S. Navy's Digital Tutor (DT) program is an ITS currently in use in the initial technical training phase for Sailors in the Information Systems Technician (IT) rating. The program is in the midst of a three-year pilot contract, being administered alongside the traditional IT training path in Pensacola, FL. DT represents one of the most advanced PL initiatives being undertaken by the military, and the program showed promising early results. However, a recent comparison of DT-trained with traditionally trained Sailors in the Fleet has raised some questions as to the effectiveness of DT, threatening the program's continued existence. In this section, I will familiarize the reader with the DT program, from conception to implementation and testing. I will then review two recent studies from the Institute for Defense Analyses (IDA) and NETC. Finally, I will reconcile the findings of these studies with cost principles and theoretical models mentioned above to recommend a course for further evaluation of the program.

Digital Tutor began as a DARPA project, intended to accelerate the development of expertise from a novice beginning state by compressing years of training and experience into a short time period of training using an ITS. In other words, the original goal of DT was to produce a significantly improved training outcome in a fixed time, but shorter than the traditional training path. The purpose of modern ITS and specifically DT is to operate as a human tutor would, except to do so cost effectively using information structures and tutorial dialogue imbedded within a computer tutor. By capturing the teachings of subject matter experts, also expert instructors, and synthesizing them for computer delivery, the system prepares students for problems they will likely encounter in the real world, in addition to imparting declarative knowledge (Fletcher & Morrison, 2014).

About half of DT's development costs went to fund the human tutor-created coursework, which was the basis for designing its software and enabling economic scalability. Once the human-tutored course was created, Content Authors worked with a Content Engineer, an AI expert with a deep understanding of DT and its software architecture, to develop the instructional flow of the program. Behind the scenes, an

Inference Engine derives the problem-solving process being used by each individual learner. These findings are passed to the Instruction Engine, which determines what elements should be presented next and when to conduct an assessment of the learner's knowledge. The Conversation Module is the interface with the student, engaging with tutorial dialogue in natural language. It also delivers the assessments as recommended by the previous two modules, and contacts a human monitor/mentor if suggested by the Recommender. All of the training is set in the context of actual systems used in the Fleet, providing a situated learning component to the process (Fletcher & Morrison, 2014).

DT uses varied approaches to instruction, depending on complexity of the problem. "Frequent and substantive dialogue interaction with learners, authentic, situated problem-solving, continual diagnostic assessment of individual learning and progress, required reflection on concepts illustrated by problem content and processes, and integration of human monitors and mentors" are components that enable deep, yet accelerated learning (Fletcher & Morrison, 2014, p. 11). Additionally, along with a monitoring function, the human instructors are considered instrumental to the DT experience, able to inject 'sea stories' or personal experiences based in the context of the Fleet. This includes familiarization time for culture, traditions and practices of the Navy.

DT differs from fully self-paced programs, in that the overall time of instruction is fixed. In DT, if a student finishes a module with extra time, they are given increasingly difficult problems, thereby achieving a higher level of understanding than the minimum. Even so, the overall pace of learning could be increased to allow all levels of students to progress quicker than traditional method. As incorporated into Navy IT A-school, the DT module shortens time-to-train by 10 weeks. While the program was developed to teach a generic IT professional training course in 18 weeks, it does not include Navy-specific elements of IT training. Therefore, the Navy version includes a 5-week hybrid course at the beginning and a 4-week hybrid course at the end, for a total time to train of 27 weeks. The traditional track requires 37 weeks to produce the same Navy Enlisted Classification (NEC) with a 6-year obligation (Department of the Navy, 2016b). The A-school course (19 weeks) for 4-year obligation sailors, a separate NEC, was not studied.

A.   INSTITUTE FOR DEFENSE ANALYSES REPORT

At four points throughout the development of DT, the Institute for Defense Analyses (IDA) conducted formative assessments of the program's effectiveness, with a fifth, summative evaluation occurring at the end using the entire 16-week program. The final assessment compared DT graduates to graduates of the traditional Information Technology Training Continuum (ITTC) and to Fleet ITs, with an average of 9.6 years of experience, in a series of exercises over 2.5 days meant to replicate complex problems of the type which might be encountered in the Fleet. Overall, the DT subjects drastically outperformed the ITTC and Fleet groups, in some cases by a substantial margin, all statistically significant. These results lead the authors to conclude that it is possible to develop real expertise in a drastically accelerated timeline and via ITS technical training only (Fletcher & Morrison, 2014).

In terms of assessing DT, the IDA evaluators sought to determine whether the program instilled in its graduates fleet-appropriate IT skills and knowledge, and whether they were superior to those provided by classroom instruction and to the skills and knowledge demonstrated by Fleet-experienced ITs. The groups being evaluated were notably small, with only 12 participants from each cohort. Overall results from the assessment weighed quite convincingly in DT's favor. DT graduates outperformed ITTC and Fleet teams on troubleshooting exercises, solving more difficult problems at a higher success rate. Additionally, DT-taught students fared much higher on knowledge tests than both sets of counterparts. In all cases, the effect sizes of DT over the status quo were noteworthy, with six of 14 being over the 2.0, "Bloom's challenge" threshold. The DT group showed weakness in only one segment of the test, the security exercise, being bested by the Fleet group, although not as badly as the Fleet group outperformed the ITTC group. This shortfall was determined to stem from the DT program's content development, where an acceptable expert in network security was not available for digitization of that module. Nonetheless, the results do suggest an overwhelming superiority of DT to ITTC for initial training of ITs.

On the other side of this result, Fleet ITs were likely at a knowledge disadvantage, as all follow on, refresher, and sustainment training is known to vary widely across the

Fleet and over time. Also, an IT's actual daily duties are often specialized within their unit, allowing for less experience across the array of potential IT jobs. In essence, students fresh out of training, whether DT or ITTC would be more competent and more comfortable with the format of the exercises seen in this study as well as with the knowledge tests. For these reasons, among others, the comparison between DT and Fleet Sailors is not adequate to conclude that the program creates expertise comparable to that of a Sailor with nearly 10 years of experience. The comparisons between the DT and ITTC groups should carry more weight in explaining the effectiveness of the program, at least from a knowledge-acquisition standpoint. In order to determine level of transfer of training to Fleet activities and any subsequent improvements in job performance and unit productivity, more rigorous research is needed with much larger sample sizes. Nonetheless, the authors contend that DT-trained graduates enter the fleet with the equivalent of seven years more of job experience than their ITTC counterparts.

Although the IDA study did not fully incorporate costs into its analysis, it did include some metrics that are worthy of discussion. While it was recognized that DT was quite expensive to develop and implement, the authors concluded that the cost in NPV of ITTC was 62 percent more per learner than DT training, or about $180,000. Assuming the above-mentioned seven-year experience gap at graduation, the difference would account for additional on-the-job training required by ITTC graduates to "catch up" with the DT cohort in experience level. The measure uses a 4 percent discount rate and sound methodology for calculating NPV (Fletcher & Morrison, 2014). Unfortunately, the assumption that DT's higher scores in the study equate to seven years of Fleet experience is problematic, as there is no accepted standard for this type of assertion. If this result is taken at face value, then perhaps the ROI justifies a high initial cost. Herein lies part of the problem with ITS like DT, they require a significant upfront investment and a longer timeframe to realize benefits. This example highlights the importance of accurate cost and ROI analyses in the assessment of programs of this type.

One area for potential analysis in the IDA study is the potential cost savings from a shorter time-to-train, as discussed previously. The study mentions the drastic time difference between the two training pipelines, at 35 versus 16 weeks, but does not

account for subsequent modifications needed for DT to fit Navy requirements, nor does it offer a calculation for potential savings. The current version of traditional IT training lasts 37 weeks, while DT is an 18-week part of a 27-week total evolution. The 10 weeks of extra time a Sailor could be in the Fleet after DT training does have value, and I will explore this idea further in the next section.

In conclusion, IDA's findings on DT are very convincing in terms of the program's effectiveness at creating expertise from a novice beginning state, but not comprehensive enough to determine its true cost-effectiveness as a replacement to traditional IT training in the Navy. In the next section, I will present findings from another report, which may offer a different perspective, and fill in some gaps left by IDA's research.

B.   NAVAL EDUCATION AND TRAINING COMMAND REPORT

In order to corroborate IDA's findings and to further assess the cost-effectiveness of the DT program, NETC was tasked with completing its own assessment in 2016. NETC's study used survey data of recent IT A-school graduates and their supervisors, designed for Kirkpatrick level three evaluation of training transfer to job performance. The study compared the 27-week course containing the 18-week DT module to the 37-week traditional, Systems Administrator (SA) course. Additionally, cost data was collected and analyzed using a prototype, Navy-developed costing model, Installation-Training Readiness Aligned Investments (I-TRAIN). The results from this two-sided cost-effectiveness analysis found that, at best, DT was equally as effective as SA, but at a cost of $32k more per student, per course. However, the benefits of getting a Sailor to the fleet 10 weeks sooner with DT were not considered (Department of the Navy, 2016b).

NETC's survey of 58 recent DT graduates, 59 SA graduates, and their supervisors identified 33 Critical Tasks for which to assess behavior change, a Kirkpatrick level 3 assessment. Respondents were asked about the frequency and proficiency with which these Critical Tasks were performed on the job, as well as the adequacy of training in preparing the graduate to perform them. Analysis of the survey results revealed that DT graduates rated themselves significantly more proficient than SA trained Sailors in only

three of the 33 Critical Tasks. The other 30 tasks bore no statistically significant difference. Conversely, the supervisors felt that SA graduates performed significantly *better* than DT graduates on four of the 33 tasks, and no different on the other 29. The descriptive statistics on the survey show that the DT and SA both thought about the same of their own proficiency, with mean scores of 3.6 and 3.4 respectively. However, supervisors definitely felt that DT grads were *less* proficient than SA, with means of 2.9 and 3.3 respectively (Department of the Navy, 2016b). This reason for this disparity is largely unexplained, but provides the basis for the finding that DT is *not* more effective than the status quo, with some evidence that it may even be less effective!

Survey results are prone to biases, and such is possibly the case with this assessment of DT. Supervisors were aware of the type of training completed by their subordinates, and this knowledge alone could have introduced undue influence to the results. In order to accurately measure the transfer of knowledge to job performance, data should be captured on the how well the Sailors perform the 33 critical tasks and how often they do so. Unfortunately, the Navy lacks these evaluation and monitoring tools, and it would likely be costly and time-consuming to implement for each specific use-case, so the survey approach must serve as a viable proxy.

NETC reported the total cost of DT training to be $88k per student, versus $56k for the SA training path (Department of the Navy, 2016b). This cost is understood to comprise essentially current-year O&M components only. However, a full review of the analysis is not possible, as many significant costs are not reflected in the I-TRAIN output. The fields for electronic classrooms and technical training equipment are empty, but presumably these amounts are far greater than the SA course and account for the majority of DT's higher costs. Although NETC's report claims to use the I-TRAIN model to capture all relevant costs, the exclusion of any cost information from the DT contract, along with a lack of characterization of fixed, variable and mixed costs preclude any further in-depth analysis into the actual cost components of the program, and prohibit the understanding of cost curve behavior, as described in section 2 of this chapter.

Finally, an analysis of the benefit of the DT's 10-week-shorter time-to-train should be conducted using standard Individuals Account programming rate. In 2007, this

rate was $148/day, which would account for a benefit of $10,360 per student. Although it does not make up the $32k difference, it does close the gap. Considering this additional savings will get us closer to understanding the full costs and benefits, assuming that the two programs produce the same quality of graduate, which is still quite open to debate.

C.   CHAPTER SUMMARY

Both studies mentioned in this chapter contain limitations that hinder a fully developed analysis of DT's costs and benefits. In the ideal cost study of educational programs, effectiveness should be determined in the most rigorous way possible, and a randomized controlled trial with sample size large enough to reduce margin of error acceptably should be considered. If the Kirkpatrick system is used to assess training effectiveness, detailed data should be collected on job performance, rather than relying on self-reported, often biased, survey responses. Every effort should be made to obtain this data, in order to offer a truly objective comparison between alternative programs and the status quo.

Cost should be considered holistically, and in like terms across programs; however, a new construct for ITS costing should be standardized. The Navy should focus on capitalizing on ITS's shorter time to train, recognizing that time savings can translate to cost savings. Neither of the DT evaluations fully address this potential. Additionally, full cost data should be transparent and available to evaluators so that an accurate and complete cost analysis may be conducted. When both effectiveness and cost sides are fully calculated, only then can programs be compared on a "cost per effect size" basis, yet neither report on DT extends to this level of examination. An ideal cost-effectiveness analysis, in essence, should simply adhere to basic standards for academic rigor and sound application of economic principles to ensure that a fully informed decision is made when addressing program continuation or replacement, as in the case of DT.

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VI. CONCLUSION AND RECOMMENDATIONS

Findings from cost studies can help to bolster the public's confidence in DOD's management of taxpayer dollars. Without such information, funding agencies are unable to make sound decisions regarding implementation of new education and training initiatives. These studies facilitate the employment of affordable programs providing acceptable net benefits over more effective programs that are not economically feasible. When educational evaluators, not economists, consider costs of programs, there are often deficiencies in terms of thoroughness, quantity, and quality. Although most do provide some justification for calculation of costs and benefits, more rigorous and in-depth concepts are usually overlooked, such as adjustments for time value of money and sensitivity analyses. This weakens the usefulness of the evaluations, slows understanding what is truly effective, and slows the policy making process (Ross et al., 2007).

Public funds should not be allocated on the basis of effect size or educational outcome alone. The costing frameworks mentioned here are useful for organizing the cost structures of training and education programs, but they are not adequate to accurately compare an ITS to the status quo. Before the true benefits of PL can be uncovered, we must understand the network effect of economies of scale, as well as recognize the need for changing infrastructure and paradigms of traditional learning institutions.

One major hurdle to adopting advanced training systems is their high cost of development. The methods used in developing the DT program are important in considering the possibility of scalability and modifications. Because the content came directly from the expertise of humans, and the system of instruction was built around their delivering specific content, this process would have to be recreated for any major modification to the current course, or in order to create a DT system for a different rating or course of study. Development costs, and especially time, would likely be prohibitive. While R&D and initial investment are sunk in the specific case of DT, these considerations would need to be factored in for any future development of a follow-on ITS program for the Navy.

In order to contend with the untenable development costs and timelines of ITS, we should continue to fund the advance of authoring systems, such as the Navy's Intelligent Tutoring Authoring and Delivery System (ITADS), so that non-expert programmers can create and edit curricula. ITADS is in early stages of development, but its objectives are to provide interactive scenario-based training, a scaffolding approach to learning, training content that is easily edited, and a virtualized training environment for all students (Department of the Navy, 2015). While this program represents an important step in the Navy's shift to a technology-enabled PL methodology, it is important to incorporate a dedicated costing program early on in the instructional design process so that decision makers may fully embrace the change from a fiscal standpoint.

Personalized learning approaches enabled by technology, such as ITS, have long demonstrated potential value as effective means of instruction, but little attention has been given to their overall cost-effectiveness (Angier & Fletcher, 1992). Rapidly advancing techniques in programming and AI, along with increasingly powerful and affordable computer hardware, make these assessments difficult. Given technology's impact on other industries in recent past, the training and education segment should follow suit, allowing new tools to become more affordable every day. While the costs of DT may yet prove unsustainable today, in a few short years the same program would almost certainly cost far less. Whether or not DT continues in its current form, we should not be discouraged from continuing to put forth effort in embracing technology to make our training and education programs second to none.

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